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COLD FLOW ANALYSIS OF FLOW OVER A RAMJET ENGINE

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ABSTRACT

Ramjet engines operate at very high altitudes and velocities creating a lot of flow complexity in and around them. A ramjet engine has been simulated at a velocity of Mach 3, to find out the streamlines and flow properties in and around the engine. The spike of the ramjet generates the required compression before the combustion process replacing the role of rotating compressors and turbines. Effect of flow properties because of shocks generated near the spike was majorly concentrated in this article. Reynolds shear stress model was used to capture the turbulence phenomena of the flow.

KEYWORDS: Ramjet & CFD Analysis

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Original Article

INTRODUCTION

Research on fast moving supersonic and hypersonic vehicles was always a popular domain of interest. Ramjets and Scramjets are air-breathing engine designs capable of maneuvering with supersonic speeds. Traveling with these speeds have the disadvantage of skin friction drag generated over the vehicle surface, resulting in the drastic increase of temperature and marginal variation of the flow properties in the engine.[8, 9]

Y. M. Timnat mentioned different types of possible solid and liquid fuelled Ramjets discussing the advantages and disadvantages of each model and their feasibility in military applications. He concluded that air-breathing ramjet with liquid fuel reduces the cost and is an efficient design. [4]

A ramjet consists of a spike used to generate shock and convert the velocity into pressure, followed by a combustion chamber where fuel is injected and a nozzle as shown in figure 1. Design shown in figure 1 is taken as the reference in this study to capture flow at high speeds.

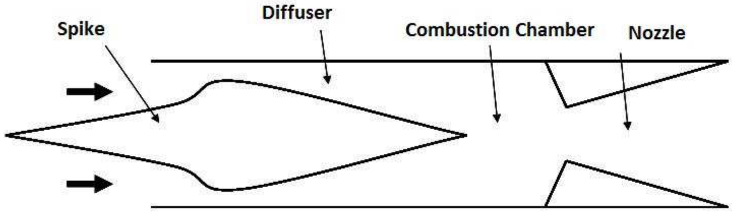

Figure 1: Schematic of Ramjet Engine [6]

Performing experimental simulations on the ramjet is a complex phenomenon. L. C Duns worth successfully mentioned the experimental blowdown facility which proved to be a cost-effective technique for

simulating ramjet. [1] A. Paull and his team had conducted an experimental investigation of the combustion process of a supersonic combustion ramjet. The liquid fuel used by them was 13% saline and 87% of hydrogen, with operational Mach number of 6. They successfully determined the thrust and drag values for the combustion process in a Scramjet. [2] J. A Linell and his team came out with a ramjet design which uses solid rocket fuel and has an operational capacity of Mach 4 and 5. [3]S. Kim and his team presented their work on ducted rocket combustor. They have investigated different types of combustors by varying the inlet angles from 90 degrees to 180 degrees. They came out with a conclusion that four inlet combustor with inlet angle of 90 degrees had better combustion efficiency. [5]

The current work majorly concentrators on flow over a spike and interior of ramjet engine without considering the combustion effects.

Problem Definition

Study model is based on design mentioned in figure 1. Mesh file have been created defining the domain clearly represented in figure 2. Inlet velocity was taken as Mach 3 and the far field conditions have been given to outlet with operating pressure of 2000 Pascal's and temperature of 200 K. These values were chosen considering the operational heights of the engine. Reynolds shear stress turbulence model was used to simulate the problem.

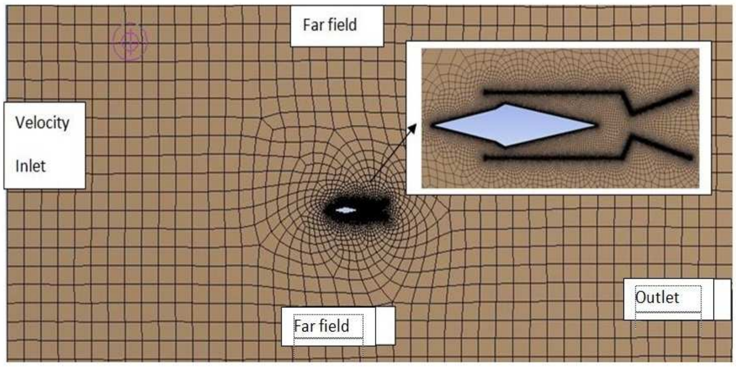

Figure 2: Problem Definition and Mesh File

For any fluid dynamic problem continuity, momentum and energy equations are the basic mathematical statements of three fundamental physical principles upon which all of fluid dynamics is based i.e. mass is conserved, *F* = ma (Newton's second law); energy is conserved. Given below are the lists of governing equations which solve the fluid domain problem.

Continuity Equation

$$D\rho/Dt + \rho\, \Delta .V = 0$$

Momentum Equation

$$\rho\, (Du/Dt) = -(\partial p/\partial x) + (\partial \tau_{xx}/\partial x) + (\partial \tau_{yx}/\partial y) + (\partial \tau_{zx}/\partial z) + \rho f_x$$

Energy Equation

$$\rho\, (De/Dt) = \rho\, q^{dot} + \partial/\partial x\, (k\, \partial T/\partial x) + \partial/\partial y\, (k\, \partial T/\partial y) + \partial/\partial z\, (k\, \partial T/\partial z) - p\, (\partial u/\partial x + \partial v/\partial y + \partial w/\partial z) + \tau_{xx} (\partial u/\partial x) + \tau_{yx} (\partial u/\partial y) + \tau_{zx} (\partial u/\partial z) + \tau_{yx} (\partial v/\partial x) + \tau_{yy} (\partial v/\partial y) + \tau_{zy} (\partial v/\partial z) + \tau_{xz} (\partial w/\partial x) + \tau_{yz} (\partial w/\partial y) + \tau_{zz} (\partial w/\partial z)$$

Navier Strokes Equation

$$\partial(\rho.u)/\partial t + \partial(\rho u^2)/\partial x + \partial(\rho uv)/\partial y + \partial(\rho uw)/\partial z = -\partial p/\partial x + \partial/\partial x\,[\lambda\,\Delta \cdot V + 2\mu\,(\partial u/\partial x)] + \partial/\partial y\,[\mu\{(\partial v/\partial x) + (\partial u/\partial y)\}] + \partial/\partial z\,[\mu\{(\partial u/\partial z) + (\partial w/\partial x)\}] + \rho\,fx$$

RESULTS AND DISCUSSIONS

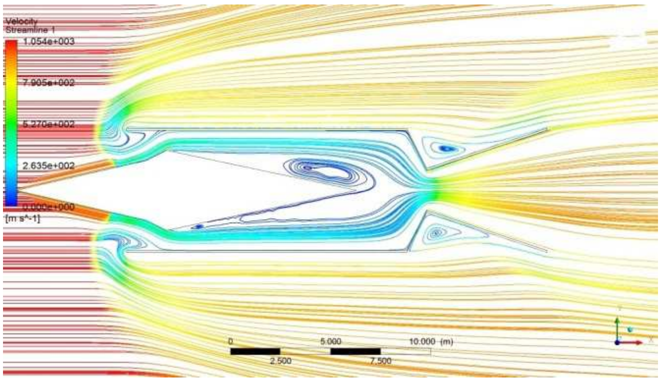

Figure 3: Velocity Streamlines Inside the Ramjet Engine

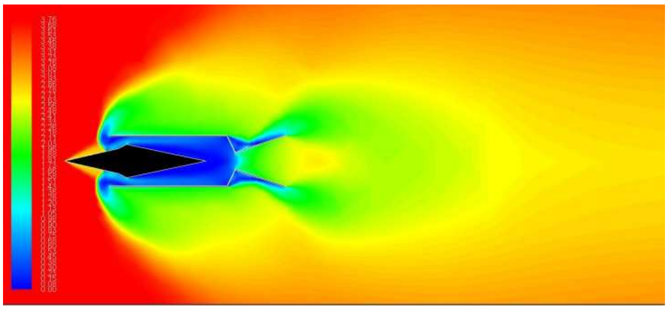

Figure 4: Contours of Mach Number

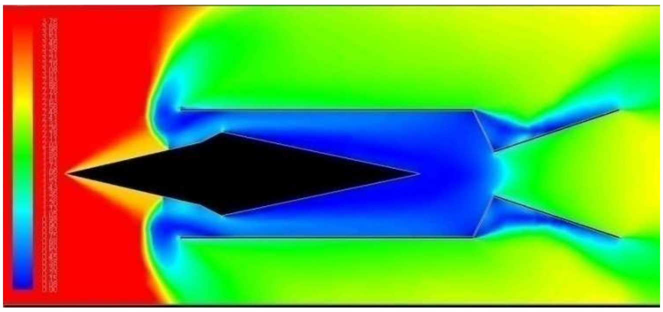

Figure 5: Shock Wave at the Beginning of the Spike

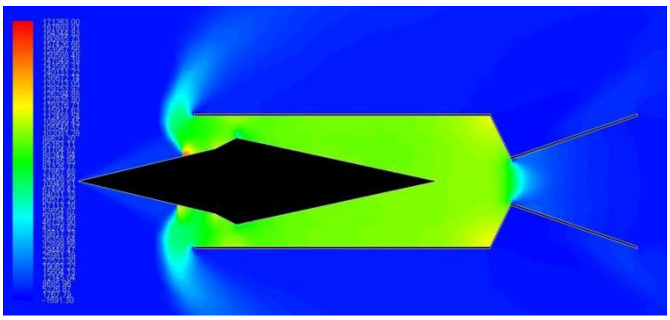

Figure 6: Contours of Static Pressure

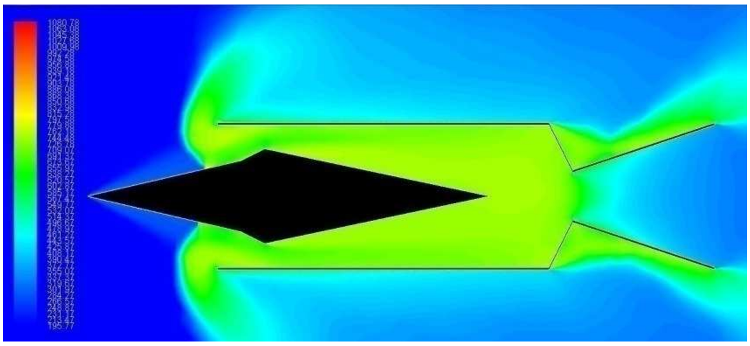

Figure 7: Contours of Static Temperature

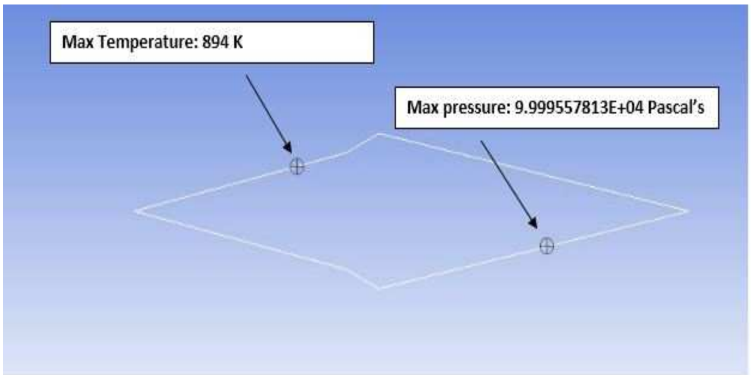

Figure 8: Location of Maximum Pressure and Temperature

The streamlines over the spike and the engine have been clearly shown in figure 3. The turbulence generated near the spike and the engine inlet can be clearly seen. Figure 4 and figure 5 show the Mach number variation inside the domain. A normal shock wave near the spike can be clearly seen in the figures. Figure 6 and Figure 7 show the pressure and temperature distribution around the spike and the supersonic engine. The locations of maximum pressure and temperature have been determined.

CONCLUSIONS

- Flow visualization had been simulated at Mach 3 for the ramjet engine.
- Locations and values of possible maximum temperatures and pressures have been determined.
- Variation of fluid properties has been studied for a ramjet engine at Mach 3.
- Determination of maximum temperatures and pressures on the engines opened doors to estimate proper material selection criteria.

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